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INACTIVATION OF MICROORGANISMS IN LIQUIDS BY HIGH ELECTRIC FIELDS

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Cases of foodborne illness caused by contaminated liquid beverages such as orange juice and apple cider still occur despite increased efforts to improve preharvest intervention. Virtually all large producers of milk, liquid egg, orange juice and apple cider pasteurize their products using heat. Heat pasteurization may detrimentally affect the quality of liquid food; hence, nonthermal pasteurization processes are actively being developed. Irradiation, high hydrostatic pressure, ultraviolet, and ultrasound processing are among those being investigated. This article presents an overview of another nonthermal process, high electric fields, that has garnered widespread attention in the past decade. A summary of the studies in our laboratory as well as those found in the literature will be presented.

PROCESS

Bacteria in foods are inactivated when they are exposed to high electric fields for extremely short times, < 1 ms, at or near ambient temperatures. High electric fields are produced by pumping the food through a narrow gap between two electrodes and applying a high voltage. Inactivation is thought to occur by electroporation (Chang et al., 1991). Cell membranes have electrical resistance and capacitance. In an electric field, a voltage is formed across the membrane. As the voltage is increased, the opposite charges on either side of the membrane are attracted to each other with greater force and the membrane becomes thinner. At a sufficiently high voltage, pores are formed in the membrane and the cell ruptures (Zimmermann, 1986). Due to the resistance of the liquid food, the electric field also raises the temperature of the food by ohmic heating. After treatment, the food is quickly cooled using a heat exchanger.

The high voltage can be applied by several different means. One method is to use direct current; however, some disadvantages of this method are that charged molecules may form a layer on the anode electrode that would eventually prevent inactivation and that undesirable electrolysis reactions may occur (Barsotti et al., 1999; Zhang et al., 1995). Using either bipolar waveforms or alternating current (AC) overcomes these problems. Bipolar waveforms are extensively used in pulsed electric fields (PEF) processing. A charging power supply produces a high voltage, and a high speed electrical switch delivers the stored energy to the electrodes. The power supply is then required to be recharged, which results in pulsed processing. An AC generator continuously provides high voltage and is the source of power for radio frequency electric fields (RFEF) processing. In our laboratory, we are developing this process and studying whether this potentially simpler method of generating high electric fields has lower capital and operating costs than those associated with PEF processing.

MICROBIAL INACTIVATION

Dunn and Pearlman (1987) were pioneers in the PEF processing of foods. *Byssochlamys fulva* conidiospores and *Neosartoria fischeri* ascospores suspended in cranberry, grape, pineapple, orange, apple, and tomato juices were PEF-processed (Raso et al., 1998). *B. fulva* conidiospores were very sensitive to PEF. However, *N. fischeri* ascospores were not inactivated by PEF, even after 40 pulses of treatment at 51 kV/cm. PEF processing of apple juice below 35°C reduced *Escherichia coli* by 5 log (Evrendilek et al., 1999). Orange juice was PEF-processed at 35 kV/cm for 59 μs at 60°C and pasteurized with hot water at 95°C for 30 s (Yeom et al., 2000). The PEF treatment prevented the growth of microorganisms at 37°C for 112 days. The PEF-treated juice retained more of the vitamin C and flavor compounds than the heat-treated juice.

In our lab, we have inactivated yeast in water at near-ambient temperatures using a radio frequency electric fields (RFEF) process (Geveke and Brunkhorst, in press). Recently, we have extended the RFEF process to inactivate *Escherichia coli* K12 in apple juice. RFEF processing at 18 kV/cm for 510 μs at 50°C reduced *E. coli* by 3 log. Raising the temperature increased inactivation. Radio frequencies of 15 and 20 kHz inactivated *E. coli* better than frequencies of 30-70 kHz.

ELECTRICAL ENERGY COSTS

The estimated energy required for pasteurization using PEF ranges from 100-400 J/ml (Barsotti and Cheftel, 1999; Schoenbach et al., 2002). Using the 400 J/ml value and the U.S. Department of Energy's data for the average industrial electric price for 2002 of $0.047/kWh, the energy cost for the high electric fields process is estimated to be $0.02/gallon. For comparison, conventional thermal pasteurization, with heat regeneration or recovery, requires only $0.002/gallon.

FUTURE WORK

Although much research has been conducted on high electric fields processing, more needs to be done. In particular, the stability of the equipment, including the metal electrodes, at longer operational times must be studied. Mold ascospores have often been reported to cause spoilage in fruit juices and are resistant to PEF. Thus, spore inactivation requires further investigation. Finally, the costs and relative merits of the various high electric fields processes must be examined with an eye toward cost reduction.

SUMMARY

High electric fields processing has been shown to inactivate microorganisms in liquid foods at relatively low temperatures. This has been demonstrated to reduce the degradation of nutrients and sensorial qualities when compared to traditional heat pasteurization. However, further research is needed before the process can be commercialized.

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